

Evidence of κ particle in $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$ *

(BES Collaboration)

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Based on a J/ψ data sample of 7.8×10^6 events at BES1, the decay of $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$ is studied and a low mass enhancement, which is believed not coming from the phase space effect or background, is visible in the $K^+ \pi^-$ invariant mass spectrum recoiling against $\bar{K}^*(892)^0$. Partial wave analysis of this channel favors this low mass enhancement being a broad 0^+ resonance with the mass and width of $771^{+164}_{-221} \pm 55$ MeV/c² and $220^{+225}_{-169} \pm 97$ MeV/c², respectively.

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The early analyses of $\pi\pi/\pi K$ scattering data showed no pole at the low mass region [1–3]. However, chiral theory predicted the existence of σ and κ [4–6]. Re-analyses of the $\pi\pi$ and πK scattering data then showed an evidence for the existence of the σ and κ particle. The pole position of κ was determined to be [4] $\sqrt{s_\kappa} = (0.875 \pm 0.075) - i(0.335 \pm 0.110) \text{ GeV}$. Motivated by the $1/N_c$ expansion, a simple model was proposed, which included a light strange scalar meson κ with the pole position at $\sqrt{s_\kappa} = (0.911 - 0.158i) \text{ GeV}$ [5]. A method of resummation of the χ_{PT} series based on the expansion of T^{-1} was studied [6], which gave the mass and width of κ particle as $m_\kappa = 770 \text{ MeV}/c^2$, $\Gamma_\kappa = 500 \text{ MeV}/c^2$. All evidences mentioned above were from $\pi\pi$

*Data analyzed were taken prior to the participation of U.S. members and Japanese members of BES Collaboration.

and πK scattering. Recently, an evidence for σ and κ has been reported in the production process by experiments [7–9]. In this work, we analyze the data of the $K\pi$ system in the production process $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$ to search for the κ .

A total of 7.8×10^6 J/ψ events, which were accumulated at the Beijing Spectrometer [10], is used to analyze $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$ channel. The preselection requires that the candidate events have four good charged tracks, which are in the polar angle region of $|\cos\theta| < 0.84$, with a total of zero net charge, without any isolated photon. The tracks must have good helix fit in the Main Drift Chamber(MDC) and have the vertices within an interaction region of $R_{xy} < 0.020\text{m}$ and $|z| < 0.20\text{m}$. Isolated photons, which are not associated with charged tracks, are identified by requiring that the energy deposited in the Barrel Shower Counter (BSC) is greater than 50 MeV, the shower starts before the layer 6 and the angle between the direction at the first layer of BSC and the developing direction of the cluster is less than 30° . All the surviving events are submitted to the 4-constraints kinematic fits for the following 5 cases: $K^+ K^- \pi^+ \pi^-$, $\pi^+ \pi^- \pi^+ \pi^-$, $K^+ K^- K^+ K^-$, $K^+ \pi^- \pi^+ \pi^-$ and $\pi^+ K^- \pi^+ \pi^-$. For each case, all the possible combinations of 4 charged tracks are tried and the one which has the least χ^2 value is chosen. To select $K^+ K^- \pi^+ \pi^-$ events, it is required that $\chi^2_{J/\psi \rightarrow K^+ K^- \pi^+ \pi^-} < 30$ and $\chi^2_{J/\psi \rightarrow K^+ K^- \pi^+ \pi^-} < \chi^2_{J/\psi \rightarrow \pi^+ \pi^- \pi^+ \pi^-}$, $\chi^2_{J/\psi \rightarrow K^+ K^- K^+ K^-}$, $\chi^2_{J/\psi \rightarrow K^+ \pi^- \pi^+ \pi^-}$ and $\chi^2_{J/\psi \rightarrow \pi^+ K^- \pi^+ \pi^-}$. The information of Time-of-Flight counter(TOF) is used for the particle identification. All particles with momentum below 500 MeV/c should have consistent particle identification with $K^+ K^- \pi^+ \pi^-$ assumption. In order to remove background events from $J/\psi \rightarrow \phi \pi^+ \pi^-$ and $J/\psi \rightarrow \bar{K}^*(892)^0 K_s^0$, events with invariant mass of $K^+ K^-$ satisfying $|M_{K^+ K^-} - 1.02| < 0.02$ GeV/c² or R_{xy} of any track greater than 0.010m are rejected. Finally, it is required that $|M_{K^- \pi^+} - 0.892| \leq 0.06$ GeV/c² to select $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$.

Fig.1 shows the scatter plot of $M_{K^+ \pi^-}$ vs. $M_{K^- \pi^+}$ after the above cuts. Two bands of $\bar{K}^*(892)^0$ and $K^*(892)^0$, corresponding to $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$ and $J/\psi \rightarrow K^*(892)^0 K^- \pi^+$ respectively, can be clearly seen. The invariant mass spectrum of $K\pi$ system is shown in Fig.2(a). Three structures can be clearly seen, with one peak at about 1.43 GeV/c², a narrow $K^*(892)^0$ signal and a broad enhancement lying under $K^*(892)^0$ peak below 1.1 GeV/c². The heavy shaded region in Fig.1 shows the $\bar{K}^*(892)^0$ side-band structure. A detailed Monte Carlo study is performed and the background from other J/ψ decay channels is found to be very small. A narrow $K^*(892)^0$ peak can also be seen in the spectrum of $\bar{K}^*(892)^0$ side-band. After the side-band subtraction, the

narrow $K^*(892)^0$ peak disappears, which indicates that it is not from the channel we are analyzing, but from the charge conjugate channel $J/\psi \rightarrow K^*(892)^0 K^- \pi^+$. The invariant mass spectrum of $K^+ \pi^-$ after the side-band subtraction is plotted in Fig.2(b), where the shaded region shows the phase space shape. The low mass broad enhancement, which is different from the shape of the phase space, is still clear. Fig.3 shows the Daliz plot, where two slope bands and one horizontal band are visible. The top slope band corresponds to the low mass enhancement which is the subject of this study, and the second slope band corresponds to the peak at 1430 MeV. The horizontal band corresponds to $J/\psi \rightarrow K_1(1410)K$ and $J/\psi \rightarrow K_1(1270)K$.

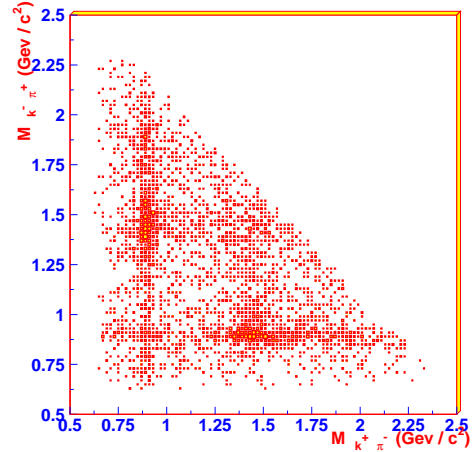


FIG. 1. Scatter plot of $M_{K^+ \pi^-}$ vs. $M_{K^- \pi^+}$. A horizontal band and a vertical band can be clearly seen, which correspond to $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$ and $J/\psi \rightarrow K^*(892)^0 K^- \pi^+$ respectively.

To further study the low mass enhancement, a Partial Wave Analysis(PWA) is performed for the $K^+ \pi^-$ invariant mass spectrum in $J/\psi \rightarrow \bar{K}^*(892)^0 K^+ \pi^-$ channel. The amplitudes of the partial waves are constructed by the covariant helicity coupling amplitude [12,13] and the low mass enhancement is treated as a s-channel resonance. The analysis method and the theoretical formula is reported in literature [13]. The total differential cross section which describes the whole decay process is

$$\frac{d\sigma}{d\Phi} = \sum_m \sum_\lambda \left| \sum_{R_i} \sum_\mu A_{R_i}(m, \lambda, \mu, M_i, \Gamma_i, \alpha) \right|^2 + BG,$$

where $A_{R_i}(m, \lambda, \mu, M_i, \Gamma_i, \alpha)$ is the helicity amplitude for the resonance R_i [13], m is the magnetic quantum number of J/ψ , λ and μ are helicities of $\bar{K}^*(892)^0$ and the resonance R_i respectively, M_i and Γ_i are the mass and width of resonance R_i , α relates to the magnitude of

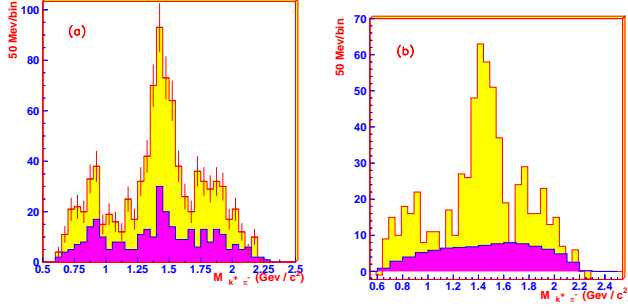


FIG. 2. (a) The invariant mass spectrum of $K^+\pi^-$ recoiling against $\bar{K}^*(892)^0$. The histogram with error bars is the data. The heavy shaded region shows the $\bar{K}^*(892)^0$ side-band structure. (b) The invariant mass spectrum of $K^+\pi^-$ after $\bar{K}^*(892)^0$ side-band subtraction. The heavy shaded region shows the phase space shape.

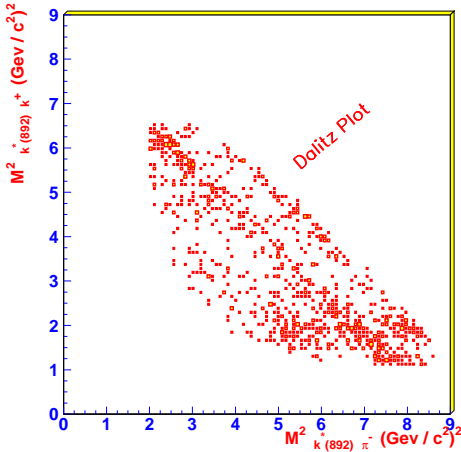


FIG. 3. Daliz plot. The top slope band corresponds to kappa and the second slope band corresponds to the peak at 1430 MeV. The horizontal band corresponds to $J/\psi \rightarrow K_1(1410)K$ and $J/\psi \rightarrow K_1(1270)K$.

each helicity amplitude and BG represents background contribution. In the fit, M_i , Γ_i and α are free parameters to be determined. The probability density function $f(M_i, \Gamma_i, \alpha)$ that describes the data sample is

$$f(M_i, \Gamma_i, \alpha) = \frac{d\sigma}{d\Phi} / \sigma$$

where σ is the total cross section of this process which is given by Monte Carlo integration. The likelihood function L is given by the joint probability density of all experimental data

$$L = \prod_{i=1}^{N_{event}} f(M_i, \Gamma_i, \alpha),$$

and the log likelihood $S = -\ln L$ is minimized in our analysis by varying parameters M_i , Γ_i and α .

In the final fit, κ , $K_0^*(1430)$, $K_2^*(1430)$, $K^*(1410)$, and the backgrounds from $K^*(892)^0 \bar{\kappa}$ and $\bar{K}^*(892)^0 K_s^0$ are considered in the $K^+\pi^-$ invariant mass spectrum, $K_1(1270)$ and $K_1(1410)$ are considered in the $\bar{K}^*(892)^0 \pi^-$ invariant mass spectrum. In this paper, we report the results using the following Breit-Wigner formula for κ particle:

$$BW_\kappa = \frac{1}{m_\kappa^2 - s - im_\kappa \Gamma_\kappa}$$

where Γ_κ is a constant. We first use a 0^+ to fit the low mass enhancement, then we test the statistical significance of its existence. If we omit it from the fit, the log likelihood value worsened by about 9, which corresponds to a 3σ statistical significance. Hence, a resonance with about 3σ statistical significance is needed. When the spin-parity is changed to 1^- or 2^+ , the log likelihood value becomes slightly worse. Therefore, its spin-parity cannot be determined definitely using BESII data, due to limited statistics. The final fit to the angular distribution of κ in the mass region of $M_{K^+\pi^-} < 1.1$ GeV is shown in Fig.4(a) and the κ contribution in $K^+\pi^-$ mass spectrum is shown in Fig.4(b). The fits to the angular distribution of the whole mass region and the $K^+\pi^-$ invariant mass spectrum are shown in Fig.4(c) and Fig.4(d) respectively.

The mass and width of the low mass enhancement are determined to be:

$$M_\kappa = 771_{-221}^{+164} \pm 55 \text{ MeV}/c^2, \Gamma_\kappa = 220_{-169}^{+225} \pm 97 \text{ MeV}/c^2.$$

through the scan of mass and width, where the first error is statistical and the second is systematic. The systematic errors of the mass and width come from the different parametrization of the Breit-Wigner formula and different fit scheme. The branching ratio can also be determined to be:

$$Br(J/\psi \rightarrow \bar{K}^*(892)^0 \kappa \rightarrow \bar{K}^*(892)^0 K^+\pi^-)$$

$$= (1.26 \pm 0.75 \pm 0.95) \times 10^{-4}$$

where the systematic error is a combination of the contributions from the different parametrization of the Breit-Wigner formula, different fit scheme, difference between Monte Carlo and data and the uncertainties of the J/ψ total number.

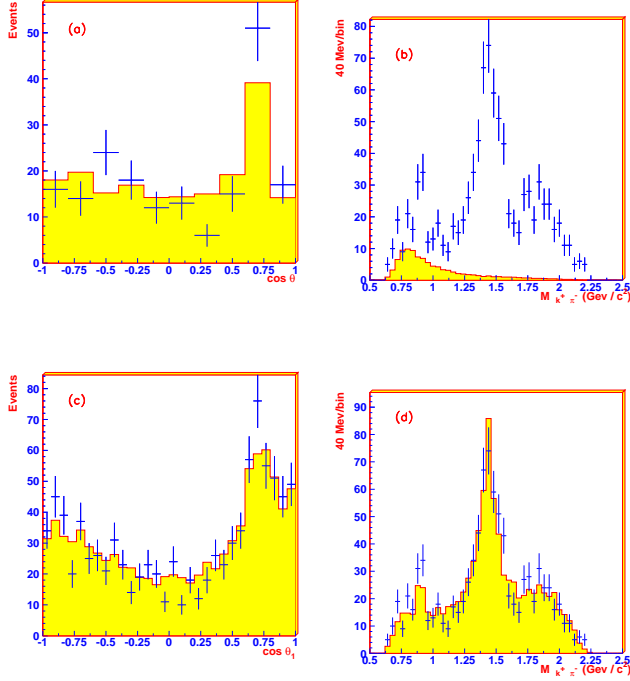


FIG. 4. (a) The final fit to the angular distribution of K^+ in $K^+\pi^-$ rest frame in κ mass region. The crosses stand for the data and histogram is our final fit. ($M_{K^+\pi^-} < 1.1$ GeV) (b) The κ -particle contribution. The crosses are the data and the shaded histogram is the contribution from κ -particle. (c) The final global fit to the angular distribution. θ_1 is the polar angle of K^+ particle in the κ rest reference. (d) The final global fit to the invariant mass spectrum.

In summary, by studying the decay of $J/\psi \rightarrow \bar{K}^*(892)^0 K^+\pi^-$, a low mass enhancement in the $K^+\pi^-$ invariant mass spectrum is observed, which is not from the phase space effect and backgrounds. In the partial wave analysis, if we treat the low mass enhancement as a resonance, we find that a resonance with 3σ statistical significance is needed in the fit with the mass and width of $771^{+164}_{-221} \pm 55$ MeV/c² and $220^{+225}_{-169} \pm 97$ MeV/c² respectively. The branching ratio is determined as $(1.26 \pm 0.75 \pm 0.95) \times 10^{-4}$. The mass and width of κ are model-dependent. Different parametrizations other than simple Breit-Wigner formula and other forms of the effective vertices may give broader width for κ .

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